

Simulation Evaluation of LTE and UMTS Wireless Communication Systems

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Abstract

The 3G communication standards (GSM/EDGE and UMTS/HSPA) have problems of capacity, latency and low speed of data transfer, and these have led to poor quality of service (QoS) from the service providers and high customer complaints. The LTE-advanced is the latest communication standard employed to increase the capacity and speed of wireless communication using a different radio interface together with core network improvements. This work aims at evaluating the performance of the LTE network such as data rate, capacity, latency and mobility in comparison with UMTS network using a simulation tool, where the model of the different networks was evaluated. The simulation software used was 'LENA, simulations were run with theoretical network parameters. The choice of network parameters was from typical values usually found in UMTS and LTE networks and consistent with MTN (Nigeria) networks for the purpose of this work. Results obtained show that LTE system using orthogonal Frequency Division Multiplexing (OFDM) and scalable bandwidth, together with more advanced MIMO schemes, provides better data rates and improved overall KPIs than the UMTS.

Keywords: LTE, Key Performance Indicators (KPIs), UMTS, LENA

1.0 Introduction

Long Term Evolution (LTE) evolves from the Third-generation technology which is based on UMTS and defines the long term evolution of the 3GPP UMTS/HSPA cellular technology [1]. The specifications of these efforts are formally known as the evolved UMTS terrestrial radio access (E-UTRA) and evolved UMTS terrestrial radio access network (E-TRAN), commonly referred to by the 3GPP project LTE [2]. It offers higher data rates, lower latency and greater spectral efficiency than previous technologies. LTE supports high performance mobile access functional up to 350Km/h with 500Km/h under consideration. Peak data rates range from 100 to 326.4Mbps on the downlink and 50 to 86.4 Mbps on the uplink depending on the antenna configuration and modulation depth. LTE is compatible with HSPA, UMTS and GSM-based technologies and hence offers a simple evolutionary path for all existing GSM and HSPA operators [3]. However, LTE's complementary core network also offers the ability to support the handover of services

between LTE and UMTS-2000 networks, making it a compelling option as a next step for UMTS-2000/EV-DO operators as well. LTE has been developed to offer both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes, enabling TD-SUMTS networks to also make a smooth transition to TDD LTE. Work on LTE began at 3GPP in 2004, with an official LTE work item started in 2006 and a completed 3GPP Release 8 specification in March 2009. Initial deployments of LTE began in late 2009. However, most of the research works on LTE started in 2007 since the first release of this standard by the 3GPP [4, 5].

LTE is composed of many new technologies compared with the previous generation of cellular systems. These new technologies are used to generate more efficiency with regards to spectrum and higher data rates as expected by designers [6].

2.0 Review of Related Literatures

Ruiz Grande in [7], analyses the Radio Resource Management (RRM) and Inter-Cell Interference Coordination (ICIC) in Heterogeneous Network, with special focus on managing the co-channel interference from the macro cell to the cell-edge users connected to the LPN (Low Power Node) through time-domain resource partitioning between the macro and LPN layers. He suggested that new applications including video live streaming or real time gaming were becoming more and more ubiquitous, requiring certain guaranteed bit rate (GBR) requirements due to the huge popularity of smart phones and the improvement of mobile networks. It was also needed, therefore, some techniques to guarantee quality of service (QoS) to users making use of these applications.

[8] in their work shows the need of using inter-cell interference management techniques, resulting in a remarkable improvement in the overall system performance. A gain of up to a factor 2.5 was achieved in terms of user throughput when using eICIC (Enhanced Inter-Cell Interference Coordination) by means of the dynamic strategy. Even the static case gave a user throughput two times higher than the case without eICIC. In addition, regarding the static and dynamic strategies studied to perform eICIC, a relative UE throughput gain of around 25% was obtained when using the dynamic case over the static one, which mainly comes from the Low Power Node - layer due to a more efficient allocation of the available resources. Ruiz Grande's work offered a positive approach towards achieving GBR and efficient capacity utilization by proper managing of interference. There is no doubt that interference limits the mobile networks capacity especially the IP networks since great proportion of useful power would be required to process the noise figures.

The author in [9] stated different values as LTE performance that depends on parameters such as system bandwidth, multi antenna schemes, FDD or TDD operation, etc. The researcher's main objective of study was to determine physical layer throughput of LTE Release 8 in different scenarios for uplink and downlink. TDD and

FDD operations were considered. Based on the system bandwidth that varies from 1.4 to 20 MHz, different amount of physical resources are available during a radio frame. Physical channels and reference signals were mapped to these resources. He maintained that by calculating the overhead of reference signals that actually do not carry information to higher layers and control channels that convey control information, the number of resource elements allotted for data transmission could be determined. Based on different modulation schemes, code rates, and number of antenna ports, the throughput for data channels could be calculated. In TDD operation there were seven configurations for time domain multiplexing of downlink and uplink data transmission that lead to different throughput values in a given channel bandwidth. His simulations were carried out with the minimum and maximum code word sizes (40 and 6144). The channel mode was assumed to be AWGN (Additive White Gaussian Noise) and normal cyclic prefix used. The LTE turbo code basic code rate was 1/3 and supported modulation schemes were QPSK, 16-QAM, and 64-QAM. Hence, the maximum throughput of different scenarios by applying the modulation scheme and puncturing code rate was calculated. His example was a case of 15 MHz bandwidth, two antenna ports, and assigning two FDM symbol for PDCCH, the number of resource elements for PDSCH was 196896 in one radio frame. So applying the modulation schemes of 64-QAM, 16-QAM and QPSK with code rates 0.92, 0.85, 0.71 respectively, the throughput was 108.868Mbps, 66.94Mbps, and 27.959Mbps for each case. The author did a good work though, but his major limitation to the maximum throughput obtained was because of the number of antennae he used which employs 2X2 MIMO. Higher throughput is expected with 4X4 MIMO which was still under development during the time of his research

[10], performed evaluations of different approaches to a practical implementation of the packet scheduling algorithm through a custom LTE system simulator using different approaches. The evaluations of three basic

packet scheduling algorithms (Maximum Rate, Proportional Fair, and Radio Resource) for the downlink of 3GPP LTE systems were considered. As a platform for the evaluation of the algorithms, a system level simulation of the LTE was developed using MATLAB. The comparison among the algorithms was performed under various channel fading models. Simulation results illustrated that the Maximum Rate (MR) algorithm achieved higher maximum rate, while Radio Resource (RR) provides maximum fairness among UEs. The PF (Proportional Fair) scheduling method, on the other hand achieved a good trade-off between the throughput and the fairness among UEs [11]. They did not do in-depth analysis and only provided a MATLAB simulation without also presenting a practical scenario. Their work however was still relevant to this work as it provided insight to some areas to be considered in the field test.

The different reviews discussed above present avenues to experimentally evaluate LTE and UMTS in urban city and then determine the desired mobile networks of not just the present age but even the near future. In this work the performance evaluation of the LTE communication standard in comparison with the UMTS (3G) standard is performed using simulation software tool, where the model of the different networks was evaluated. The simulation software used was LENA, simulations were run with theoretical network parameters. The choice of network parameters was from typical values usually found in UMTS and LTE networks and consistent with MTN (Nigeria) networks for the purpose of this work.

3.0 Materials and Methods

This work evaluates the performance of LTE network and UMTS network. The method adopted involved modelling of UMTS and LTE network nodes, their interfaces, properties, protocols, latency, data rates and handover techniques using software. The next approach is developing mathematical models that emulate the behaviour of the different message signal flows that occur during the voice and data processes. The mathematical model however

was more useful in voice/data handover KPI than other KPIs and consequently the model was used for just handover. Based on these mathematical models, equations were derived for the service interruption time of the handover scheme. The resulting equations along with their mathematical models could be coded using any intuitive programming language such as, MATLAB or C++. The software tool used for this research was NS-3 LENA.

NS-3 LENA simulations were run with theoretical network parameters. The choice of network parameters was from typical values usually found in UMTS and LTE networks and consistent with MTN networks for the purpose of this work.

Simulations were done in two phases. The first phase was with static network parameters. I.e. a single user terminal, with predefined mathematical behaviour and network parameters was communicating with the UMTS and LTE network nodes that also had static behaviour.

The second simulation was with a dynamic network. I.e. the behaviour of the network nodes was modelled in real time. For example as the user terminal accessed the UMTS and LTE network nodes, the nodes process messages from other user terminals in real time.

3.1: Theoretical Analysis of UMTS and LTE Networks

(a) UMTS Network Architecture and Protocol

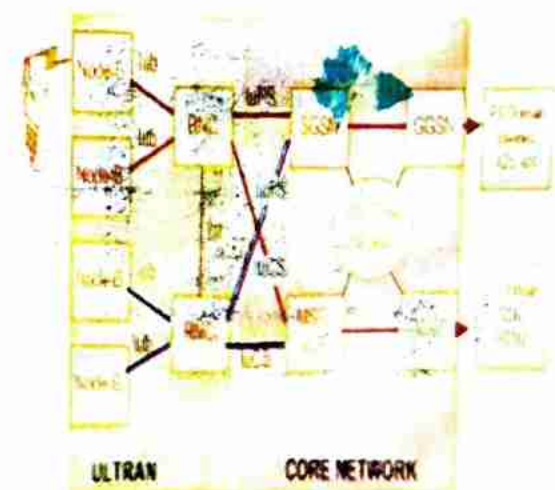


Figure 1: UMTS Network Architecture

The UMTS architecture shown in figure 1, comprises of the UE, the base station (known as the Node B), the Radio Network Controller (RNC) which together make up the UTRAN. Also shown are the Core Network and the associated interfaces [12, 13].

The UE: Consists of the Mobile Equipment (ME) and Universal Subscriber Identity Module (USIM). The ME is a radio terminal used for radio communication over the Uu interface. The Uu interface allows for communication between the UE and the UTRAN. The USIM is a smartcard that holds subscriber identity and performs authentication algorithms.

- * Node B: Is the UMTS base station and converts the data flow between the Iub and Uu interfaces. The Iub interface is used to carry messages between the Node B and the RNC. The Node B also performs radio resource management functions.

- * The Radio Network Controller (RNC): controls radio resources (Node Bs).

- * Home Location Register (HLR): is a database in the CN that stores the master copy of the user's service profile.

- * Mobile Services Switching Centre/Visitor Location Register (MSC/VLR): is the switch and database that serve the UE in its current location for Circuit-Switched services. The MSC switches the CS services while the VLR holds a copy of the visitor's user profile.

- * Gateway MSC (GMSC): is the switch through which the UMTS connects to other CS networks.

- * Serving GPRS Support Node (SGSN) is similar to MSC/VLR except that it is used for packet switched services.

- * Gateway GPRS Support Node (GGSN) is similar to the GMSC but in relation to packet switched services.

(b) LTE Network Architecture and Protocol

In LTE the term Evolved Packet Core (EPC) [6, 8, 9], is used to refer to the new core network. The following nodes are present in the EPC as seen in figure 2.

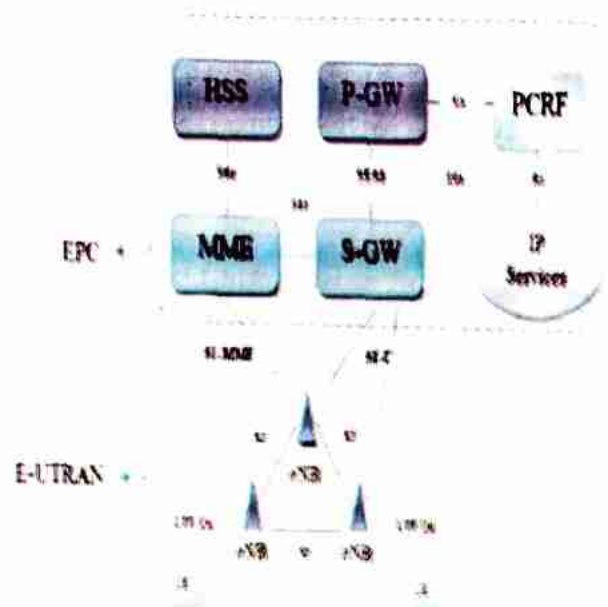


Figure 2: EPS Architecture

- * Serving Gateway, SGW: gateway that terminates the interface towards E-UTRAN. For each UE associated with the EPS, at a given point of time, there is a single Serving GW. The S-GW performs several functions but mainly handles mobility management within the LTE network and other 3GPP technologies. SGSN could be connected to the S-GW to enable the smooth running with UMTS.

- * Packet Data Network Gateway, PGW: The PDN GW is the gateway which terminates the SGI interface towards the PDN. The SGI interface is the reference point between the PDN gateway and the packet network. If a UE is accessing multiple PDNs, there may be more than one PDN GW for that UE; however a mix of S5/S8 connectivity and Gn/Gp connectivity is not supported for that UE simultaneously.

- * Mobility Management Entity, MME deals with control plane signalling, mobility management and idle-mode. The MME is connected to the S-GW and P-GW via the S11 interface.

- * Policy and Charging Rules Function, PCRF is concerned with QoS policy and charging policy.

(c) Comparison of LTE and UMTS Physical layer

Basically, LTE physical layer is built based on UMTS/HSPA releases. The first LTE release covers aspects of HSDPA and HSUPA e.g. Hybrid Automatic Repeat request (HARQ), base

station-based scheduling and link adaptation, multi-antenna downlink transmission [11, 12, 13]. Table 1 shows the comparison of the physical layer of the LTE and UMTS systems.

Table 1: LTE and WCDMA physical layer comparison

Feature	LTE	HSUPA	HSDPA
Feature	LTE	HSUPA	
Multiple access	OFDMA SC-FDMA	WCDMA	WCDMA
Bandwidth range	1.4-20MHz	5-10MHz	5-10MHz
Fast power control	No	Yes	No (associated DCH only)
Soft handover	No	Yes	No (associated DCH only)
Adaptive modulation	Yes	Yes	Yes
BTS-based scheduling	Time/Frequency	Time/Code	Time/Code
Fast LI HARQ	Yes	Yes	Yes

3.2 Simulation Testbed

The simulation for LTE1800 is done as below. Simulations are carried out with the minimum and maximum codeword sizes (40 and 6144). The channel mode is assumed to be AWGN and normal cyclic prefix is used. The LTE turbo code basic code rate is 1/3 and supported modulation schemes are QPSK, 16-QAM, and 64-QAM.

Simulation parameter

1. Network type: FDD LTE
2. Frequency Band: 1800MHz

3. Number of Sites :1

4. Site Configuration :2 sector

5. MIMO : 2T4R

6. Propagation Model : Cost-Hata231

Tables 2 and 3 show the typical simulation parameters for the LTE and UMTS Networks respectively.

Table 2: Summary of LTE Parameters

Parameter	Value(s)
FFT Length	2048
Maximum Number of RBs	100
Duplex Mode	FDD, TDD
Channel Type	AWGN
FEC Coding Scheme	Turbo coding, R=1/3
Modulation	QPSK, 16-QAM, 64-QAM
Frame Period	10ms
Subcarrier spacing	15kHz
Cyclic prefix	Normal
Code Block Sizes	40, 6144
Code Rates	0.33 to 0.92
Antenna Diversity	SISO, 2x2 MIMO, and 4x4 MIMO
Maximum iteration of turbo code	10
Wrap up depth for turbo code	6

Min BER	10^{-9}
Max BER	10^{-4}
Number of Errors	300

Table 3: Main UMTS Parameters

Property	Description
Multiple access method	DS-UMTS
Duplexing method	Frequency division duplex/time division duplex
Base station synchronization	Asynchronous operation
Chip rate	3.84 Mcps
Frame length	10ms
Service multiplexing	Multiple services with different quality of service requirements multiplexed on one connection
Multi-rate concept	Variable spreading factor and multi-code
Detection	Coherent using pilot symbols or common pilot
Multuser detection, smart antennas	Supported by the standard, optional in the implementation

4.0: Implementation and Results

Figure 3 demonstrates the BER values versus SNR respectively for QPSK, 16-QAM and 64-QAM modulation schemes for minimum and maximum codeword size. It is shown that the

SNR gains for longer frame size is less than short frame sizes. Throughput calculations are based on the FER values that are applied to maximum and minimum codeword sizes.

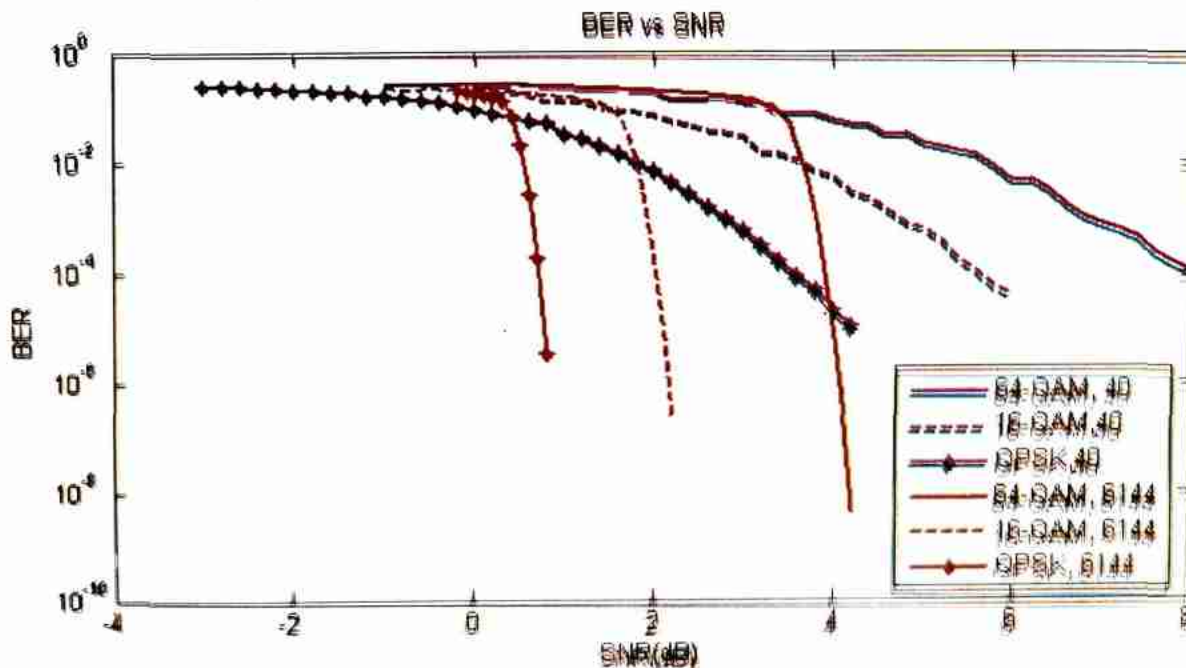


Figure 3: BER vs. SNR for QPSK, 16-QAM, and 64-QAM schemes (LTE)

Figure 4 shows FDD downlink throughput in Mbps for one and four antenna ports and 1.4 MHz and 20MHz of system bandwidth in different modulation schemes. In these simulations, one OFDM symbol is assigned to

PDCCH. The maximum throughput in 1.4MHz of system bandwidth, one antenna port, two OFDM symbols assigned for PDCCH and 64-QAM modulation with 0.71 code rate is 3.935 Mbps; in 20 MHz bandwidth, four antenna

ports. 64-QAM data modulation, 276.32 Mbps of data throughput is possible based on 0.84 puncture code rate; however, if this puncture code rate increases to the maximum of 0.92 the throughput of 299.122 Mbps can be achieved. When two antenna ports are used for downlink data transmission, considering the least resource

elements assigned to control information (one OFDM symbol), 64-QAM data modulation, 0.92 puncturing code rate, and 20MHz system bandwidth, 158.366 Mbps of throughput is possible (maximum throughput in 2x2 antenna port scenario).

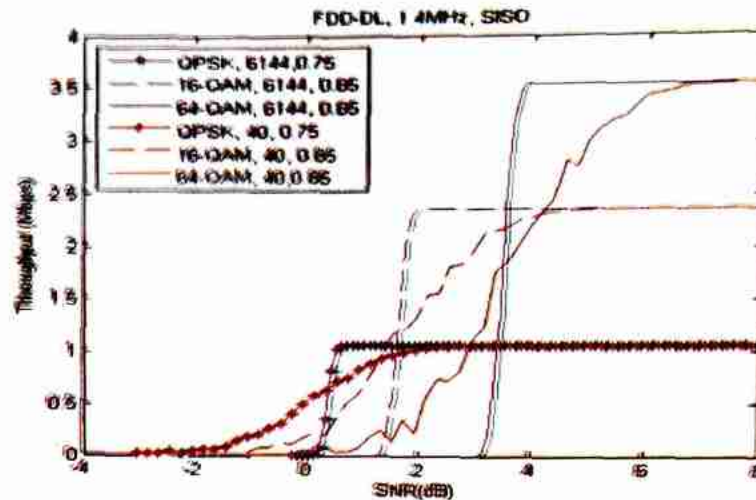


Figure 4: FDD PDSCH throughputs (1.4MHz)

We can calculate the maximum throughput of different scenarios by applying the modulation scheme and puncturing code rate. These scenarios in FDD downlink can include different channel bandwidths (1.4, 3, 5, 10, 15, 20 MHz), antenna ports (1, 2, or 4), control channel overhead (1 to 4 OFDM symbols), and code rates (0.15 to 0.92). For example, in case of 15 MHz bandwidth, two antenna ports, and assigning two OFDM symbol for PDCCH, the number of resource elements for PDSCH is 196896 in one radio frame. So applying the modulation schemes of 64-QAM, 16-QAM and QPSK with code rates 0.92, 0.85, 0.71 respectively, the throughput is 108.868 Mbps, 66.94 Mbps, and 27.959 Mbps for each case. Besides the throughput calculation, we can calculate the overhead of each control channel or even reference signals. For instance in case of 20 MHz system bandwidth, and 4 antenna ports, the PDCCH overhead is 1.06 Mbps, 4.26 Mbps, 7.46 Mbps for 1, 2 and 3 OFDM symbols assigned to this channel and considering that the

modulation is QPSK for this channel and the code rate is 1/3. This calculation excludes PCFICH that occupies 16 OFDM resource elements of the first OFDM symbol since the code rate for this channel is 1/6. So for the maximum data throughput of 299.122 Mbps, PDCCH overhead is 1.06 Mbps which is 2.37% of the total physical layer.

UMTS does not have a scalable bandwidth like LTE so the simulation results are based on 5 MHz system bandwidth; one transmit and two receive antenna (SIMO). LTE downlink performance is evaluated based on channel estimation method; however, high code rate and multi antenna schemes are not considered in performance analysis. Figure 5 shows the performance simulation results. This simulation is based on EVA channel and shows 5 Mbps, 13 Mbps, and 31 Mbps of throughput for QPSK 1/3, 16 QAM 1/2 and 64QAM 3/4 respectively.

One antenna port is assumed.

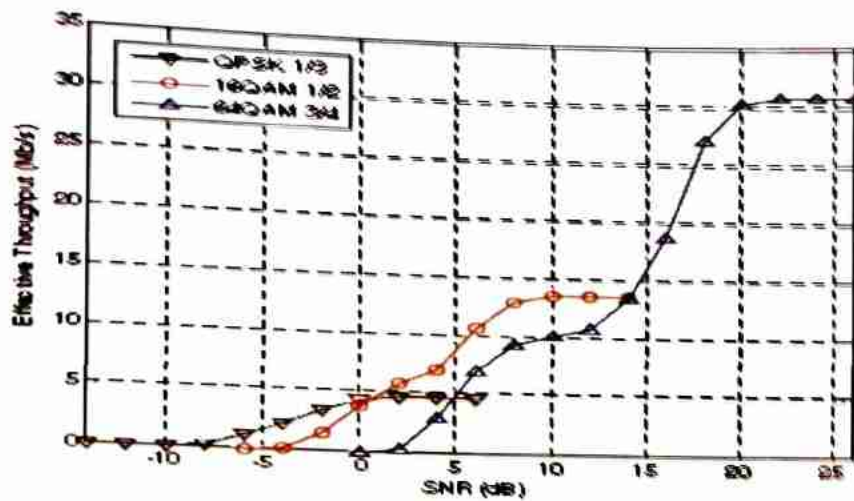


Figure 5: FDD PDSCH Throughputs (5MHz)

The throughput comparison of LTE and UMTS is based on Downlink FDD operation. The physical layer structure is compared here and gives the overhead for control channels for both LTE and UMTS standards. The results show better radio performance for LTE due to less overhead. In terms of SNR gain both standards have the same performance, but in respect to the throughput, LTE outperforms UMTS.

Speed test results on fig 6 below show that both technologies offer same latency results as Ping was completed at same period ~36ms. LTE at

10MHz offers 2.73 times as much speed offered by UMTS at 5MHz on the downlink and 5.67 times more than UMTS on the uplink. Note that UMTS which is based on WCDMA has maximum bandwidth of 5MHz, LTE utilizing OFDMA on the downlink can offer up to 20MHz depending on operators licensed bandwidth.



LTE Band – 2100MHz.

Installed Bandwidth – 10MHz

UMTS Band – 2100MHz.

Installed Bandwidth – 5MHz

Figure 6 LTE Vs UMTS Speed Test

4.1 Ping Test Result Analysis for Latency check

Fig 7 and fig 8 show 32 bytes and 1000 bytes ping test result carried out on LTE and UMTS network respectively to determine the latency

(round trip delay). For 32 a bytes ping test with LTE network, the minimum latency was 32ms while the maximum was 45ms. The average latency was 33ms. For 32 bytes ping test with UMTS network, the minimum latency was 44ms while the maximum was 78ms and the average was 55ms.

For a 1000 bytes ping test with LTE network, the minimum latency was 34ms while the maximum was 50ms. The average latency was 36ms. For 1000 bytes ping test with UMTS network, the minimum latency was 45ms while the maximum was 191ms and the average was 91ms.

```
C:\Documents and Settings\108189196>ping 192.168.10.2 -l 32 -n 20

Pinging 192.168.10.2 with 32 bytes of data:

Reply from 192.168.10.2: bytes=32 time=45ms TTL=127
Reply from 192.168.10.2: bytes=32 time=33ms TTL=127
Reply from 192.168.10.2: bytes=32 time=33ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=34ms TTL=127
Reply from 192.168.10.2: bytes=32 time=33ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=33ms TTL=127
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Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127
Reply from 192.168.10.2: bytes=32 time=32ms TTL=127

Ping statistics for 192.168.10.2:
    Packets: Sent = 20, Received = 20, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 32ms, Maximum = 45ms, Average = 33ms
```

Fig 7a: LTE User plane delay tests (Ping 32 bytes)

```
C:\Users\epkoeke>ping 192.168.10.2 -t,32 -n 20

Pinging 192.168.10.2 with 32 bytes of data:
Reply from 192.168.10.2: bytes=32 time=52ms TTL=58
Reply from 192.168.10.2: bytes=32 time=57ms TTL=58
Reply from 192.168.10.2: bytes=32 time=51ms TTL=58
Reply from 192.168.10.2: bytes=32 time=60ms TTL=58
Reply from 192.168.10.2: bytes=32 time=58ms TTL=58
Reply from 192.168.10.2: bytes=32 time=53ms TTL=58
Reply from 192.168.10.2: bytes=32 time=62ms TTL=58
Reply from 192.168.10.2: bytes=32 time=55ms TTL=58
Reply from 192.168.10.2: bytes=32 time=56ms TTL=58
Reply from 192.168.10.2: bytes=32 time=51ms TTL=58
Reply from 192.168.10.2: bytes=32 time=54ms TTL=58
Reply from 192.168.10.2: bytes=32 time=62ms TTL=58
Reply from 192.168.10.2: bytes=32 time=51ms TTL=58
Reply from 192.168.10.2: bytes=32 time=49ms TTL=58
Reply from 192.168.10.2: bytes=32 time=63ms TTL=58
Reply from 192.168.10.2: bytes=32 time=61ms TTL=58
Reply from 192.168.10.2: bytes=32 time=48ms TTL=58
Reply from 192.168.10.2: bytes=32 time=78ms TTL=58
Reply from 192.168.10.2: bytes=32 time=48ms TTL=58
Reply from 192.168.10.2: bytes=32 time=44ms TTL=58

Ping statistics for 192.168.10.2:
    Packets: Sent = 20, Received = 20, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 44ms, Maximum = 78ms, Average = 55ms
```

Figure 7b: UMTS User plane delay tests (Ping 32 bytes)

Pinging 192.168.10.2 with 1000 bytes of data:

```
Reply from 192.168.10.2: bytes=1000 time=50ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=30ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=26ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=34ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
Reply from 192.168.10.2: bytes=1000 time=36ms TTL=127
```

Ping statistics for 192.168.10.2:

Packets: Sent = 20, Received = 20, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 24ms, Maximum = 50ms, Average = 36ms

Figure 8a: LTE User plane delay tests (Ping 1000 bytes)

C:\Users\seokoeke>ping 192.168.10.2 -l 1000 -n 20

Pinging 192.168.10.2 with 1000 bytes of data:

```
Reply from 192.168.10.2: bytes=1000 time=45ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=51ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=57ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=191ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=101ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=64ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=154ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=148ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=148ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=65ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=81ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=73ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=65ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=74ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=65ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=63ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=81ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=100ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=99ms TTL=58
Reply from 192.168.10.2: bytes=1000 time=102ms TTL=58
```

Ping statistics for 192.168.10.2:

Packets: Sent = 20, Received = 20, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 45ms, Maximum = 191ms, Average = 91ms

5.0 Conclusion

LTE is the generation of wireless communication that has capabilities of changing the way through which wireless world connects people. As mentioned above, although there are many similarities between UMTS (3G) and LTE (4G), there are also many differences between these two technologies. The main difference between UMTS and LTE is the use of technology. There are number of technologies which comes under 3G including WCDMA and HSPA. WCDMA supports both data and voice services enhanced features include optimal performance for single and aggregated 5MHz carrier. It also enables Multiple Input Multiple Output (MIMO) scheme for data rate improvements currently being allowed for a theoretical maximum of 42Mbps in downlink (DL) and 12Mbps in uplink (UL).

In LTE, different technologies are involved, both in air interface and core network, aiming at bringing higher spectral efficiency and network closer to the world of Internet Protocol(IP).LTE uses Orthogonal Frequency Division Multiplexing (OFDM) for radio access, together with more advanced MIMO schemes, providing for theoretical maximum data rates of 300Mbps in DL and 75Mbps in UL. MIMO has a growing usage trend among many high data rate technologies in order to provide great efficiency, such as in Wi-Fi and other wireless and cellular technologies. LTE uses MIMO to increase the throughput. OFDM changes a frequency selective fading channel into multiple flat fading sub channels facilitating easy equalization. MIMO deploys multiple antennas on the receiver and transmitter to take advantage of multipath effect to transmit additional data without causing interference. MIMO schemes employed in LTE vary slightly on both DL and UL in order to get the low terminal cost.

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